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DEVELOPMENT OF FINE DIAMETER HIGH-PURITY WIRE FROM ZONE-REFINED BERYLLIUM

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A. G. Gross, Jr.
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Final Report*
January, 1963

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*Addendum No. 1, January, 1963. This addendum to the final report contains room temperature tensile properties for the wire which was produced from zone-refined beryllium.

RESEARCH AND DEVELOPMENT
The Brush Beryllium Co.
CLEVELAND, OHIO

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The Brush Beryllium Company
Cleveland, Ohio

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I. INTRODUCTION

This addendum to the final report presents the results of the tensile testing which was performed on as-drawn specimens from crystal D. These specimens have been described on pages 50 and 51 of the final report.

II. EXPERIMENTAL PROCEDURE

Stock was cropped from each end of sample D. 2b at each of 12 diameters which ranged from 0.03176-inch to 0.00407-inch. These wires were cut into tensile specimens and were tested in the "as-drawn with lubricant" condition at room temperature.

III. RESULTS AND DISCUSSION

The results of the tensile testing are presented in Table VI.

The values from Table VI have been plotted on logarithmic coordinates and these graphs are shown in Figures 21, 22, and 23 for yield strength, tensile strength, and elongation, respectively. Also in these figures are values for wire which was fabricated from commercially-pure, block-pressed beryllium. The block-pressed data are the same as were shown previously in Figures 18 and 19 of the final report. Note that Figures 21, 22, and 23 include the 95% confidence limits on the mean values for everything except commercially-pure elongation. The 95% confidence limits on the commercially-pure elongation are exceptionally broad. They are approximately ± 1.00% elongation.

The yield and tensile strength data for commercially-pure beryllium plot such that a straight line may be struck through the points with fair confidence. There are indications that a curve with two or more inflections might be a better choice, but the confidence limits are too broad to justify this choice in preference to the straight line.

The yield and tensile strength data for zone-refined beryllium plot such a curve with at least one inflection is the mandatory choice of a first approximation. A dashed straight line which has the same slope as the commercially-pure line has been struck through the zone-refined data to emphasize the similarity of general trends.

The pronounced inflection in the zone-refined data suggest that the inflections which are indicated by the commercially-pure data are probably real also. These inflections infer that the strengthening sequence proceeds by unique stages which are separated by pauses for structural adjustments. The structural adjustments would probably be changes in the subgrain (or "cell") configuration, or a recovery thereof, thus decreasing the effective grain size while renovating the capacity for subsequent work-hardening. The major component of the driving force for such changes would be the wire-drawing strain-energy. This strain energy would be diverted from producing strain-hardening so as to be consumed for the structural adjustment.

Such an interpretation might be dismissed as invalid for either or both of the following reasons:

TABLE VI

ROOM TEMPERATURE TENSILE RESULTS FOR AS-DRAWN WIRE FROM CRYSTAL D

			Mean Value[c] ±95% Confidence Limits (for the Mean[d])		
Wire[a] Diameter (inch)	Wire[b] Drawn Strain	No. of Tests	Yield at 0.2% Offset (x 10^3 psi)	Tensile Strength (x 10^3 psi)	Elongation (%)
0.03176	1.75	6	62.9 ± 2.3	70.3 ± 2.7	0.28 ±0.13
0.02712	2.06	7	57.6 ± 1.2	73.9 ± 1.3	0.65 ±0.08
0.02197	2.48	7	63.9 ± 1.9	81.0 ± 0.7	0.75 ±0.13
0.01688	3.01	8	69.2 ± 2.5	86.8 ± 1.7	0.81 ±0.15
0.01297	3.54	8	79.6 ± 1.5	98.1 ± 2.3	0.98 ±0.17
0.01051	3.95	14	86.1 ± 2.6	104.8 ± 1.9	1.21 ±0.13
0.00807	4.50	15	84.4 ± 1.5	98.4 ± 2.1	1.11 ±0.17
0.00654	4.90	15	83.3 ± 1.3	96.3 ± 1.8	1.02 ±0.16
0.00588	5.11	14	82.2 ± 2.7	93.9 ± 2.2	0.78 ±0.17
0.00530	5.32	14	82.8 ± 3.1	94.3 ± 4.1	0.71 ±0.16
0.00477	5.54	10	87.1 ± 3.9	95.5 ± 4.7	0.54 ±0.12
0.00407	5.85	14	80.9 ± 2.5	87.0 ± 2.8	0.34 ±0.05

(Continued on next page.)

TABLE VI (Continued)

ROOM TEMPERATURE TENSILE RESULTS FOR AS-DRAWN WIRE FROM CRYSTAL D

FOOTNOTES: [a] Wire was tested in the "as-drawn with lubricant" condition. A 1.00-inch gage length was used for all diameters except for the 0.03176-inch diameter where a 1.40-inches gage length was used. A strain rate of 0.100 in./in./min. was employed in an Instron model TT-C-L machine.

[b] Measured from last anneal. Wire Drawn Strain is expressed as Ln (reduction ratio).

[c] Average for specimens from each end of the length of wire being drawn. Statistical analysis indicated no difference between ends and the results from both ends at each sampled diameter were averaged to yield one mean value.

[d] Note that the confidence limit is on the "mean value", not on the distribution of the individual determinations.

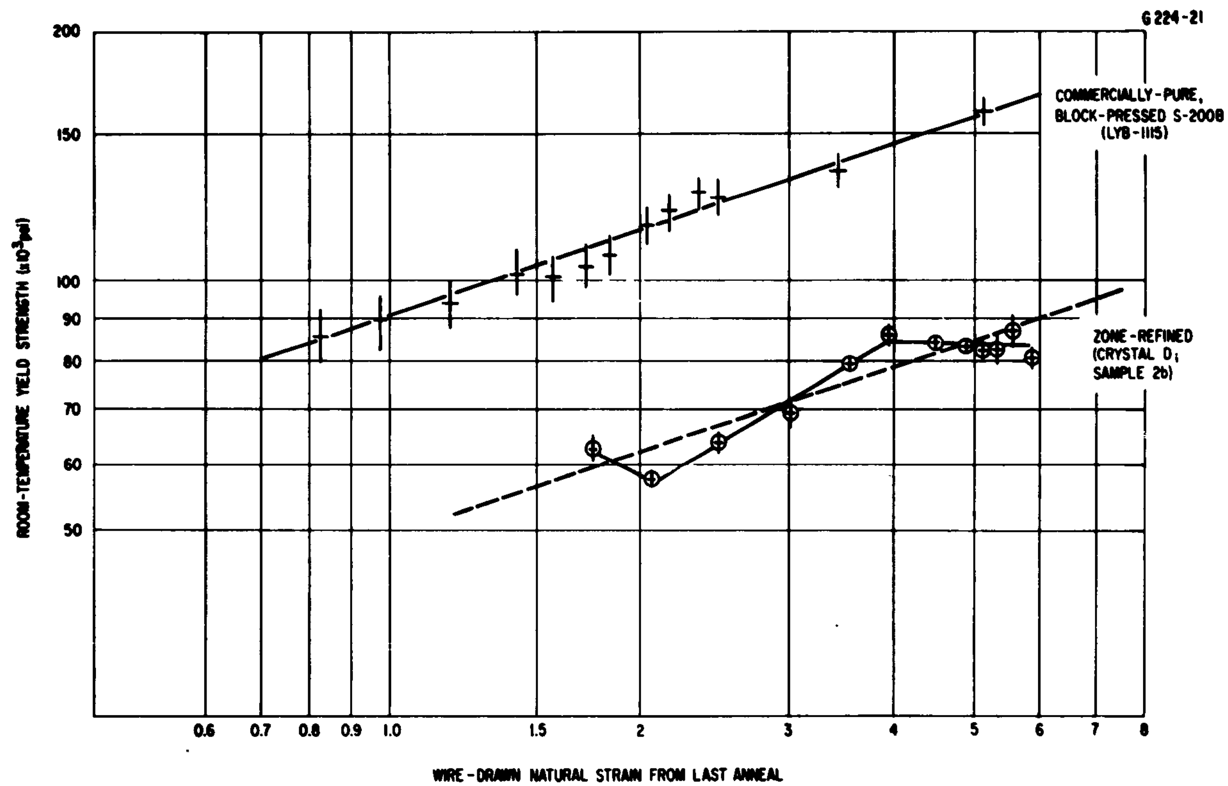

Fig. 21 The Variation in As-Drawn Yield Strength With Wire-Drawing Strain

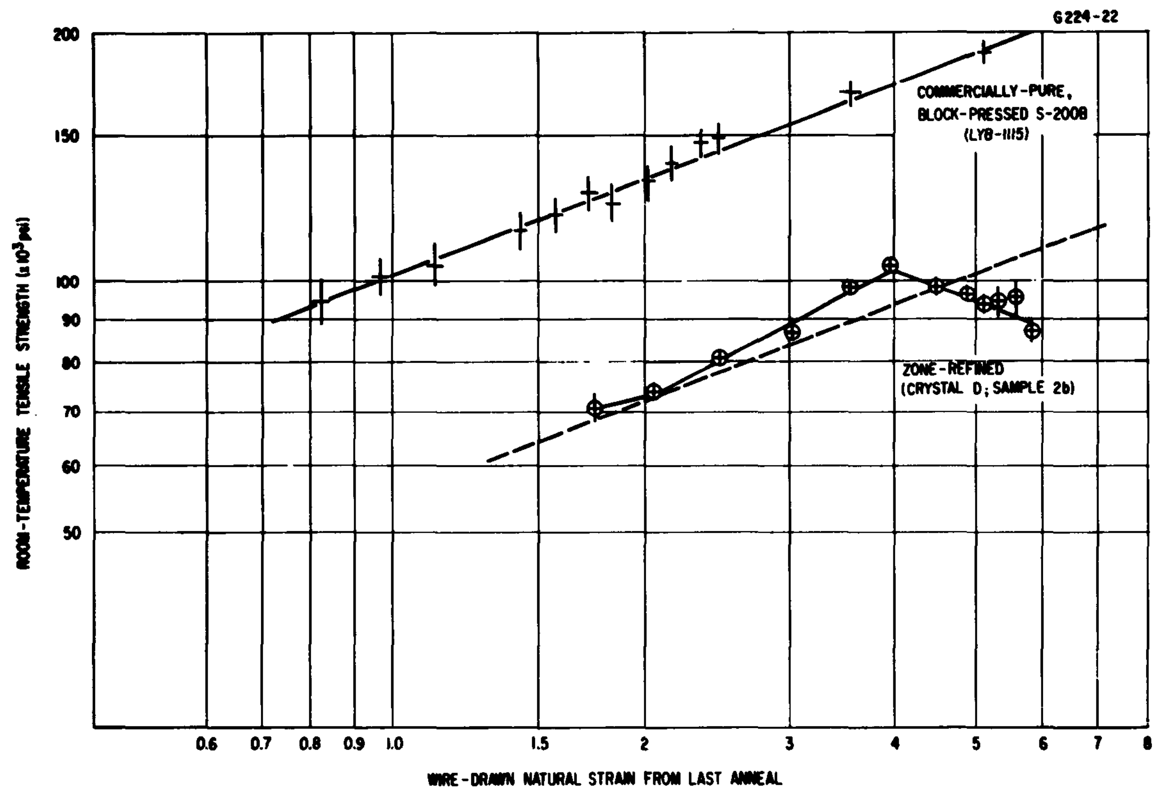

Fig. 22 The Variation in As-Drawn Tensile Strength With Wire-Drawing Strain

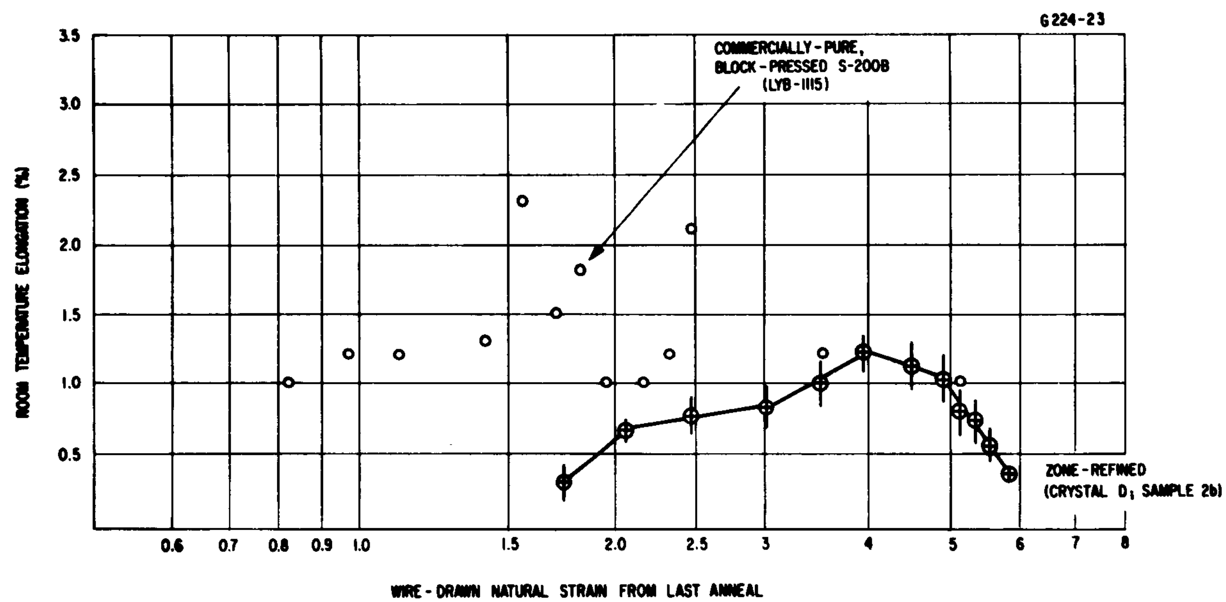

Fig. 23 The Variation in As-Drawn Ductility With
Wire-Drawing Strain

1. The data for the zone-refined beryllium show only one strengthening stage. This would not be enough to allow conclusions to be drawn with much confidence.

2. The ductility of the zone-refined material falls continuously at the highest wire-drawing strains.

With respect to the first reason it might be noted that the commercially-pure data may be viewed as consisting of three strengthening stages if one accepts the existence of inflections in these data. Further, the zone-refined data may be taken to consist of one strengthening stage plus the beginning of second stage if the datum point at the highest strain level is either discounted or assigned to some other effect. The fact that the zone-refined material has fewer structural adjustments per increment of strain than does the commercially-pure material would be compatible with the larger magnitude of each adjustment and with the higher mobility of dislocation arrays (such as grain boundaries) in zone-refined beryllium.

The second reason is perhaps the stronger of the two because it is difficult to rationalize within the structural adjustment interpretation and because it might be taken to suggest that damage such as microcracks is being introduced at the high strain levels. Of course there is the plausibility that the decrease in the effective grain size (during structural adjustment) proceeds in the zone-refined material to the point where even a small amount of subsequent tensile deformation at room temperature induces serious dislocation pile-ups at the newly formed effective grain boundaries. This could lead to crack formation and fracture at low values of room-temperature tensile strain. Such an argument would be supported by the continuous decrease in the tensile-minus-yield-strength difference at the higher strain levels.

This structural-adjustment interpretation has been presented for the purpose of suggesting concepts for future work. The data which are reported herein do not justify a confident acceptance of this interpretation. It is hoped that work which is in progress under Navy Contract No. NOw 63-0137-c will extend the data (at least for the commercially-pure wire) to higher strain levels. This extension may help to clarify the details of the strengthening path but will not necessarily clarify the interpretation of this path.

There are several points which are illuminated by the results in this report. First, the difference in work-hardening rate between commercially-pure and zone-refined beryllium which was indicated in Figures 18 and 19 of the final report is not real. The data for the lowest level of strain for crystal 31 were apparently non-representative. Upon reviewing the information at this strain level, it was found that the two tensile specimens from which the data were generated were tested in the Virgo descaled and pickled condition while the rest of the test samples were not cleaned after wire drawing. Thus, the comments in the first paragraph on page 49, final report, should be accepted as valid.

Another point is the relative strengths of the three materials. The commercially-pure beryllium is the strongest and the 7-pass, zone-refined beryllium is the weakest. The 6-pass, zone-refined beryllium is at an intermediate strength level. This sequence is the expected one and increases the confidence in the strength data for wire from crystal 31.

The final point is that the wire which was fabricated from zone-refined beryllium has about the same as-drawn ductility at room temperature as does the commercially-pure wire.

IV. SUMMARY AND CONCLUSIONS

Wires from zone-refined crystal D were tensile tested at room temperature. These wires were tested in the as-drawn-with-lubricant condition. Tensile properties of the wire from crystal D were determined as a function of wire-drawing strain.

These tensile data were compared to similar data for commercially-pure beryllium wire.

It was found that, on the average, the zone-refined beryllium work-hardened at about the same rate as did commercially-pure beryllium. The room temperature strength level of the zone-refined material was about half that of the commercially-pure wire. Room temperature ductility in the as-drawn condition was not very purity-sensitive.